Why study Earth System Science?

Humankind has only become aware of its potential impact on the earth in the past half-century. Indeed humans have become a important agent of geomorphic change. It has been asserted that human activity now involves an annual flux of materials equal to that of plate tectonics (Bloom, 1991). Thus, our the impacts of humans are not small, nor have they been benign. While it is quite easy to visualize the impact of human activity on a local scale and even on a regional scale, the fact that human activities could have global consequences is harder to imagine. The first real wake-up call on the global consequences of our activities was arguably that of ozone depletion.

A Short History of the Greenhouse Effect

However, a larger potential problem, and one with much greater economic and social implications is the concern over fossil fuel emissions and the so-called 'greenhouse effect'. In 1997, Physics Today published an article detailing the history of the debate over the potential consequences of fossil fuel emissions (Weart, 1997).

The potential warming effect of fossil fuel emissions was first recognized by Svante Arrhenius in 1896. Arrhenius was a physical chemist who discovered the relationship between the activation energy of a chemical reaction and its absolute temperature - the famous Arrhenius equation. He argued that doubling the amount of carbon dioxide in the atmosphere would raise the air temperature by 5-6° C. Limitations in his knowledge made the calculations incorrect, but this should not distract from the fact that he correct identification of the problem. The idea was based on the idea first proposed by Joseph Fourier in 1822 that the Earth is kept warm by the trapping of heat by the atmosphere; akin to the trapping of heat by the glass panes in a greenhouse. Like Arrhenius, Fourier is better known for other scientific accomplishments. He developed the concept of the Fourier series. [Later in the course we will see that the so named 'greenhouse effect' is nothing like the complicated processes occurring in a horticultural greenhouse]. However, Arrhenius calculations were considered implausible for the next 50 years.

In 1938, Guy Steward Callendar, a steam technician with the British Electrical and Allied Industries Research Association assert that since the 1890's carbon dioxide in the atmosphere had increased 10%. He also claimed that this explained the warming over the same period. His assertions were also meet with considerable skepticism. Two major issues were used to argue against this:

1) There is 50 times more carbon dioxide in the oceans than in the atmosphere and it was thought that any additional carbon produced by fossil fuel emissions would be simply absorbed by the oceans.
2) By far the most important greenhouse gas is water vapor. At this time it was known that water vapor absorbed outgoing longwave radiation at the same wavelengths as carbon dioxide [we will discuss the physics of greenhouse gases later] so even if additional carbon dioxide was in the atmosphere it would have no effect.
3) There was a disconnection between people studying climate and the rest of the scientific community. A climatologist was someone involved in describing climate usually based on ground instrumental data. Such information was most valuable to agriculture, civil engineering etc. Thus it was done by individuals out of mainstream meteorology. This separation is not fully mended today. My former advisor, as one example, makes a clear distinction between those people who collect the climate data and analyze it and those scientists looking at physical processes. The relegation of the study of climate to essentially second class status slowed the study of climate change.

Well both of these assertions turned out to be flawed. At the time physicists were only interested in where certain molecules absorbed energy (the science is called spectroscopy) and not how much they absorbed. Gilbert Plass (a theoretical physicist at John Hopkins University) used new techniques developed during WWII to determine that carbon dioxide would indeed lead to a greater interception of outgoing longwave radiation. Incidentally, these calculations required the computational power of newly developed computers.

Secondly, studies of the uptake of carbon dioxide were done by Roger Revelle of the Scripps Institute of Oceanography. The imputus behind many of these early studies was understanding the uptake of C-14 produced by nuclear bomb tests. Revelle's work should that the oceans would adjust to the to match the higher carbon dioxide levels in the atmosphere so the uptake of carbon dioxide by the oceans was less than expected by earlier workers.

In the 1950's, Charles Keeling also of Scripps began measuring carbon dioxide in the atmosphere. This research was an outgrowth of funding that became available with the international Geophysical Year (which I believe is 1957-1958). Despite, funding problems over the years, Keeling has maintained a continuous record of atmospheric carbon dioxide to the present day. The Keeling curve as it is known is now the icon of the 'greenhouse effect'.

It has been only in the past 10 years that a serious interdisciplinary effort has been made to understand the complex feedbacks in the earth system controlling the amount of carbon dioxide in the atmosphere. More than anything else, the concern over fossil fuel emissions and potential warming and associated consequences have fueled and focused Earth System Science Research during the past decade.

The major synthesis of the huge body of research on all aspects of Climate Change is entitled Climate Change 1995 - The Science of Climate Change. Contributions of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). This report and two companion reports describing human impacts and mitigation strategies were perhaps the major underpinnings of the Third Conference of Parties to the Framework Convention on Climate Change held in Kyoto Japan last year.

Perhaps the most important component of the report is the Summary to Policy Makers. This brief (5 page) summary is aimed at explaining the scientific state of knowledge concerning this issue to policy makers. This section has been formally approved - meaning it was subjected to detailed line-by-line discussions before the wording was finalized. The text of this section is included below.

The important scientific questions discussed here in this document are extremely relevant to current Earth System Science because they are those considered most relevant and as we shall see, these overriding issues are then expressed by the funding priorities of scientific organizations within the United States. Hence, Earth Scientists should be aware of how they relate to the larger issues. For instance, within NASA Earth System Science research falls under the program formally known as Mission to Planet Earth (MTPE). Recently for some reason, a decision has been made to rename the program and the new name is Earth Science. In my branch all scientists must demonstrate how each publication they write are relevant to these goals which reflect the larger issues in the IPCC report we will now discuss.

Summary for Policymakers: The Science of Climate Change - IPCC Working Group I

Contents

Considerable progress has been made in the understanding of climate change1 science since 1990 and new data and analyses have become available.

Greenhouse gas concentrations have continued to increase

Increases in greenhouse gas concentrations since pre-industrial times (i.e., since about 1750) have led to a positive radiative forcing[2] of climate, tending to warm the surface and to produce other changes of climate.

- The atmospheric concentrations of greenhouse gases have increased significantly (values for 1992):
  - inter alia, carbon dioxide (CO_2) 30%
  - methane (CH_4) 145%
  - nitrous oxide (N_2O) 15%

- These trends can be attributed largely to human activities
  - fossil-fuel use
  - land-use change
  - agriculture.

- The growth rates of CO2, CH4 and N2O concentrations were low during the early 1990s. While this apparently natural variation is not yet fully explained, recent data indicate that the growth rates are currently comparable to those averaged over the 1980s.
- The direct radiative forcing of the long-lived greenhouse gases (2.45 Wm^{-2}) is due primarily to increases in the concentrations (values for 1992)
- CO_2 (1.56 Wm^{-2})
- CH_4 (0.47 Wm^{-2}) and
- N_2O (0.14 Wm^{-2}) (values for 1992).

- Many greenhouse gases remain in the atmosphere for a long time (for CO_2 and N_2O, many decades to centuries), hence they affect radiative forcing on long time-scales.
- The direct radiative forcing due to the CFCs and HCFCs combined is 0.25 Wm^{-2}. However, their net radiative forcing is reduced by about 0.1 Wm^{-2} because they have caused stratospheric ozone depletion which gives rise to a negative radiative forcing.
- Growth in the concentration of CFCs, but not HCFCs, has slowed to about zero. The concentrations of both CFCs and HCFCs, and their consequent ozone depletion, are expected to decrease substantially by 2050 through implementation of the Montreal Protocol and its Adjustments and Amendments.
- At present, some long-lived greenhouse gases (particularly HFCs (a CFC substitute), PFCs and SF_6) contribute little to radiative forcing but their projected growth could contribute several per cent to radiative forcing during the 21st century.
- If carbon dioxide emissions were maintained at near current (1994) levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about 500 ppmv (approaching twice the pre-industrial concentration of 280 ppmv) by the end of the 21st century.
- A range of carbon cycle models indicates that stabilization of atmospheric CO concentrations at 450, 650 or 1000 ppmv could be achieved only if global anthropogenic CO_2 emissions drop to 1990 levels by, respectively, approximately 40, 140 or 240 years from now, and drop substantially below 1990 levels subsequently.
- Any eventual stabilized concentration is governed more by the accumulated anthropogenic CO_2 emissions from now until the time of stabilization than by the way those emissions change over the period. This means that, for a given stabilized concentration value, higher emissions in early decades require lower emissions later on. Among the range of stabilization cases studied, for stabilization at 450, 650 or 1000 ppmv, accumulated anthropogenic emissions over the period 1991 to 2100 are 630 GtC3, 1030 GtC and 1410 GtC, respectively (approximately 15% in each case). For comparison the corresponding accumulated emissions for IPCC IS92 emission scenarios range from 770 to 2190 GtC.
- Stabilization of CH_4 and N_2O concentrations at today's levels would involve reductions in anthropogenic emissions of 8% and more than 50% respectively.
- There is evidence that tropospheric ozone concentrations in the Northern Hemisphere have increased since pre-industrial times because of human activity and that this has resulted in a positive radiative forcing. This forcing is not yet well characterized, but it is estimated to be about 0.4 Wm^{-2} (15% of that from the long-lived greenhouse gases). However, the observations of the most recent decade show that the upward trend has slowed significantly or stopped.

Anthropogenic aerosols tend to produce negative radiative forcings

- Tropospheric aerosols (microscopic airborne particles) resulting from combustion of fossil fuels, biomass burning and other sources have led to a negative direct forcing of about 0.5 Wm^{-2}, as a global average, and possibly also to a negative indirect forcing of a similar magnitude. While the negative forcing is focused in particular regions and subcontinental areas, it can have continental to hemispheric scale effects on climate patterns.
- Locally, the aerosol forcing can be large enough to more than offset the positive forcing due to greenhouse gases.
- In contrast to the long-lived greenhouse gases, anthropogenic aerosols are very short-lived in the atmosphere, hence their radiative forcing adjusts rapidly to increases or decreases in emissions.

Climate has changed over the past century

At any one location, year-to-year variations in weather can be large, but analyses of meteorological and other data over large areas and over periods of decades or more have provided evidence for some important systematic changes.

- Global mean surface air temperature has increased by between about 0.3 and 0.6°C since the late 19th century; the additional data available since 1990 and the re-analyses since then have not significantly changed this range of estimated increase.
- Recent years have been among the warmest since 1860, i.e., in the period of instrumental record, despite the cooling effect of the 1991 Mt Pinatubo volcanic eruption.
- Night-time temperatures over land have generally increased more than daytime temperatures. Regional changes are also evident. For example, the recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic ocean. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season.
- Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature.
- There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators (e.g., fewer frosts in several widespread areas; an increase in the proportion of rainfall from extreme events over the contiguous states of the USA). Some of these changes have been toward greater variability; some have been toward lower variability.
- The 1990 to mid-1995 persistent warm-phase of the El Nino-Southern Oscillation (which causes droughts and floods in many areas) was unusual in the context of the last 120 years.

The balance of evidence suggests a discernible human influence on global climate

Any human-induced effect on climate will be superimposed on the background "noise" of natural climate variability, which results both from internal fluctuations and from external causes such as solar variability or volcanic eruptions. Detection and attribution studies attempt to distinguish between anthropogenic and natural influences. "Detection of change" is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change. "Attribution" is the process of establishing cause and effect relations, including the testing of competing hypotheses.

Since the 1990 IPCC Report, considerable progress has been made in attempts to distinguish between natural and anthropogenic influences on climate. This progress has been achieved by including effects of sulphate aerosols in addition to greenhouse gases, thus leading to more realistic estimates of human-induced radiative forcing. These have then been used in climate models to provide more complete simulations of the human-induced climate-change "signal". In addition, new simulations with coupled atmosphere-ocean models have provided important information about decade to century time-scale natural internal climate variability. A further major area of progress is the shift of focus from studies of global-mean changes to comparisons of modelled and observed spatial and temporal patterns of climate change.

The most important results related to the issues of detection and attribution are:

- The limited available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as any other century since at least 1400 A.D. Data prior to 1400 are too sparse to allow the reliable estimation of global mean temperature.
- Assessments of the statistical significance of the observed global mean surface air temperature trend over the last century have used a variety of new estimates of natural internal and externally-forced variability. These are derived from instrumental data, palaeodata, simple and complex climate models, and statistical models fitted to observations. Most of these studies have detected a significant change and show that the observed warming trend is unlikely to be entirely natural in origin.
- More convincing recent evidence for the attribution of a human effect on climate is emerging from pattern-based studies, in which the modelled climate response to combined forcing by greenhouse gases and anthropogenic sulphate aerosols is compared with observed geographical, seasonal and vertical patterns of atmospheric temperature change. These studies show that such pattern correspondences increase with time, as one would expect, as an anthropogenic signal increases in strength. Furthermore, the probability is very low that these correspondences could occur by chance as a result of natural internal variability only. The vertical patterns of change are also inconsistent with those expected for solar and volcanic forcing.

- Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.

Climate is expected to continue to change in the future

The IPCC has developed a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and fuel mix during the period 1990 to 2100. Through understanding of the global carbon cycle and of atmospheric chemistry, these emissions can be used to project atmospheric concentrations of greenhouse gases and aerosols and the perturbation of natural radiative forcing. Climate models can then be used to develop projections of future climate.

- The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased our confidence in their use for projection of future climate change. Important uncertainties remain, but these have been taken into account in the full range of projections of global mean temperature and sea-level change.
- For the mid-range IPCC emission scenario, IS92a, assuming the "best estimate" value of climate sensitivity4 and including the effects of future increases in aerosol, models project an increase in global mean surface air temperature relative to 1990 of about 2°C by 2100. This estimate is approximately one-third lower than the "best estimate" in 1990. This is due primarily to lower emission scenarios (particularly for CO2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario (IS92c) with a "low" value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1°C by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a "high" value of climate sensitivity gives a warming of about 3.5°C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Regional temperature changes could differ substantially from the global mean value. Because of the thermal inertia of the oceans, only 50-90% of the eventual equilibrium temperature change would have been realized by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilized by that time.
- Average sea level is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice-sheets. For the IS92a scenario, assuming

the "best estimate" values of climate sensitivity and of ice-melt sensitivity to warming, and including the effects of future changes in aerosol, models project an increase in sea level of about 50 cm from the present to 2100. This estimate is approximately 25% lower than the "best estimate" in 1990 due to the lower temperature projection, but also reflecting improvements in the climate and ice-melt models. Combining the lowest emission scenario (IS92c) with the "low" climate and ice-melt sensitivities and including aerosol effects gives a projected sea-level rise of about 15 cm from the present to 2100. The corresponding projection for the highest emission scenario (IS92e) combined with "high" climate and ice-melt sensitivities gives a sea-level rise of about 95 cm from the present to 2100. Sea level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilized by that time, and would continue to do so even beyond the time of stabilization of global mean temperature. Regional sea-level changes may differ from the global mean value owing to land movement and ocean current changes.

- Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes.
- All model simulations, whether they were forced with increased concentrations of greenhouse gases and aerosols or with increased concentrations of greenhouse gases alone, show the following features: greater surface warming of the land than of the sea in winter; a maximum surface warming in high northern latitudes in winter, little surface warming over the Arctic in summer; an enhanced global mean hydrological cycle, and increased precipitation and soil moisture in high latitudes in winter. All these changes are associated with identifiable physical mechanisms.
- In addition, most simulations show a reduction in the strength of the north Atlantic thermohaline circulation and a widespread reduction in diurnal range of temperature. These features too can be explained in terms of identifiable physical mechanisms.
- The direct and indirect effects of anthropogenic aerosols have an important effect on the projections. Generally, the magnitudes of the temperature and precipitation changes are smaller when aerosol effects are represented, especially in northern mid-latitudes. Note that the cooling effect of aerosols is not a simple offset to the warming effect of greenhouse gases, but significantly affects some of the continental scale patterns of climate change, most noticeably in the summer hemisphere. For example, models that consider only the effects of greenhouse gases generally project an increase in precipitation and soil moisture in the Asian summer monsoon region, whereas models that include, in addition, some of the effects of aerosols suggest that monsoon precipitation may decrease. The spatial and temporal distribution of aerosols greatly influences regional projections, which are therefore more uncertain.

- A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days.
- Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events. Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g., tropical cyclones.
- Sustained rapid climate change could shift the competitive balance among species and even lead to forest dieback, altering the terrestrial uptake and release of carbon. The magnitude is uncertain, but could be between zero and 200 GtC over the next one to two centuries, depending on the rate of climate change.

There are still many uncertainties

Many factors currently limit our ability to project and detect future climate change. In particular, to reduce uncertainties further work is needed on the following priority topics:

- Estimation of future emissions and biogeochemical cycling (including sources and sinks) of greenhouse gases, aerosols and aerosol precursors and projections of future concentrations and radiative properties.
- Representation of climate processes in models, especially feedbacks associated with clouds, oceans, sea ice and vegetation, in order to improve projections of rates and regional patterns of climate change.
- Systematic collection of long-term instrumental and proxy observations of climate system variables (e.g., solar output, atmospheric energy balance components, hydrological cycles, ocean characteristics and ecosystem changes) for the purposes of model testing, assessment of temporal and regional variability, and for detection and attribution studies.

Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve "surprises". In particular, these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behaviour. Progress can be made by investigating non-linear processes and sub-components of the climatic system. Examples of such non-linear behaviour include rapid circulation changes in the North Atlantic and feedbacks associated with terrestrial ecosystem changes.

Footnotes:

[1]Climate change in IPCC Working Group I usage refers to any change in climate over time whether due to natural variability or as a result of human activity. This differs from the usage in the UN Framework Convention on Climate Change where "climate change" refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

[2]A simple measure of the importance of a potential climate change mechanism. Radiative forcing is the perturbation to the energy balance of the Earth-atmosphere system (in Watts per square metre [Wm^{-2}]). 3 1 GtC = 1 billion tonnes of carbon. 4 In IPCC reports, climate sensitivity usually refers to the long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent CO2 concentration. More generally, it refers to equilibrium change in surface air temperature following a unit change in radiative forcing ($^{o}C/Wm^{-2}$).

United States Global Change Research Program (USGCRP)

[The following section has been extracted from Our Changing Planet The FY 1998 U.S. Global Change Research Program. The full text is available on the WWW at: http://www.gcrio.org/ocp98/toc.html

The United States, through the U.S. Global Change Research Program, supports research needed to characterize and understand global environmental change and to provide answers to important questions about the Earth system, how it is changing, and the implications of global change for society and the natural systems on which society depends.

The underlying premise of the USGCRP is that the development of an appropriate relationship between human society and the global environment is inextricably linked to an improved understanding of the systems that are undergoing change in response to natural and human-influenced processes.

USGCRP Participating Agencies
Department of Agriculture (USDA)
Department of Commerce (DOC/NOAA, DOC/NIST)
Department of Energy (DOE)
Department of Health and Human Services
Department of the Interior
Environmental Protection Agency (EPA)
National Aeronautics and Space Administration (NASA)
National Science Foundation (NSF)
Smithsonian Institution (SI)
Tennessee Valley Authority (TVA)

The USGCRP Focus: Four Key Global Change Issues

In response to the development of scientific understanding and research capabilities, the USGCRP is focusing research efforts on four areas of Earth system science that are of significant scientific and practical importance:

- Seasonal to Interannual Climate Variability, with the goal of obtaining a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad.

- Climate Change over Decades to Centuries, with the goal of understanding, predicting, and assessing changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors, and providing the scientific information needed by society to address these changes.
- Changes in Ozone, UV Radiation, and Atmospheric Chemistry, with the goal of understanding and characterizing the chemical changes in the global atmosphere and their consequences for human well-being.
- Changes in Land Cover and in Terrestrial and Aquatic Ecosystems, with the goal of providing a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial and aquatic ecosystems resulting from human-induced and natural influences.

Seasonal to Interannual Climate Variability

Progress toward the Seasonal to Interannual Climate Variability goal will provide improved predictions that can, among other direct benefits, help farmers maintain their agricultural productivity in spite of extreme climatic events such as droughts and floods; help water resource managers to ensure reliable water deliveries, limit flood damage, and maintain optimal reservoir levels; help in planning fishery harvests; and help foresters allocate resources effectively to safeguard forests (and the public) from major fires during droughts.

In FY98 and over the next several years, the USGCRP will build on its initial successes and support research activities geared to achieve the following objectives:

- Improve skills in predicting climate fluctuation, particularly over the United States
- Monitor the tropical Pacific Ocean in order to better determine its influence on climate, and to improve predictions
- Map global precipitation and its relationship to climate fluctuations
- Incorporate field data into models in order to improve forecasts of climate variability
- Assess human vulnerability to climate variations and identify options for adaptation based on improved information from predictions
- Establish a network of research centers to improve forecast model development and diagnostics, and the application of predictive information to socio-economic planning processes.

Climate Change over Decades to Centuries

Progress toward the Climate Change over Decades to Centuries goal is providing information needed by decisionmakers considering adaptive or mitigative responses to the projected changes in climate and the associated environmental and societal impacts. The information will also assist planners and managers with responsibilities for the design of infrastructure and other major facilities, sustained management of natural resource-based systems, and long-term planning in the financial sector.

In FY98 and over the next several years, the USGCRP will continue to address significant uncertainties through support for research activities oriented toward the following key objectives:

- Quantify the natural and human-induced factors that change atmospheric composition and radiation
- Characterize natural climate variability and the factors contributing to decadal and longer period climate fluctuations
- Improve quantitative representations of climate system mechanisms and feedback processes
- Improve scenario-driven predictions of climate change and identification of the human-induced component in the recent climate record
- Develop improved measures of the sensitivity, vulnerability, and adaptability of natural systems and project the consequences of climate change and long-term variations of the climate
- Develop improved measures of the sensitivity, vulnerability, and adaptability of socio-economic systems, and project the societal implications of climate change and long-term natural variability.

Changes in Ozone, UV Radiation, and Atmospheric Chemistry

Progress toward the Changes in Ozone, UV Radiation, and Atmospheric Chemistry goal will provide information to assist policymakers in protecting human health, preserving the cleansing and shielding qualities of the atmosphere, and ensuring that new chemical compounds released into the atmosphere do not lead to adverse consequences from changes in atmospheric composition.

The USGCRP's atmospheric chemistry research has the following objectives:

- Monitor atmospheric chemical composition trends and the human-influenced emissions that cause them
- Understand the stratospheric ozone variations during the coming most-vulnerable decade
- Monitor changes in surface UV radiation, and quantify exposure and consequences to the biosphere and human health
- Develop a predictive understanding of the chemistry of the global troposphere
- Characterize the radiative links between atmospheric chemistry and climate change
- Assess the scientific understanding of the future of the ozone layer and of the role of human-influenced chemistry in the radiative forcing of climate change.

Changes in Land Cover and in Terrestrial and Aquatic Ecosystems

Progress toward the Changes in Land Cover and in Terrestrial and Aquatic Ecosystems goal will provide a stronger scientific basis for developing environmental and natural resource practices that are environmentally sound and practical, and that will ensure ecosystems can be managed to yield sustainable benefits to humankind.

Achieving the goal of research on changes in land cover and in terrestrial and aquatic ecosystems will require meeting several key objectives:

- Document the current patterns and past changes in global land cover
- Understand natural and human-induced influences that lead to changes in land cover, land use, coastal alterations, and terrestrial and aquatic ecosystems
- Predict the extent and consequences of changes in land-cover, land-use, and ecosystem processes, especially as they relate to the sustainability of natural resources and economic development
- Quantify exchanges of trace gases between the atmosphere and the terrestrial biosphere, with particular emphasis on the processes controlling carbon sources and sinks
- Observe and document the current patterns and past changes in chemical, physical, and biological activity in the oceans, especially those that are relevant to understanding the exchange of carbon dioxide with the atmosphere
- Understand and analyze the chemical, physical, and biological processes that regulate ocean uptake and release of atmospheric carbon dioxide and that control biological productivity in the oceans, and develop the predictive capabilities needed to ensure the sustainability of marine resources.

The Proposed USGCRP Budget For FY98

The proposed FY98 USGCRP budget totals $1.878 billion. After adjusting so that comparable programs are included in the compilation (see discussion below), the FY98 request is an increase of $68 million (3.8%) from the estimated FY97 budget. As outlined in this edition and in the FY97 edition of *Our Changing Planet*, the USGCRP budget supports scientific research on key global change environmental issues, including seasonal to interannual climate variability; climate change over decades to centuries; changes in ozone, UV radiation, and atmospheric chemistry; and changes in land cover and in terrestrial and aquatic ecosystems.

The USGCRP budget supports global change research integrating activities, including observing and monitoring global change; global change data, products, and information services; research on Earth system science and on human contributions and responses to global change; international research cooperation; and global change education and communication.

The figures and tables in Appendix A provide the following:

- USGCRP budgets for FY96-FY98 by Federal agency

- USGCRP budgets for FY96-FY98 by Budget Function

- USGCRP activities on global change environmental science issues by agency, indicating which agencies make a "broad- based" scientific contribution in each area and which agencies participate by making a more "focused" contribution

- USGCRP activities on issues central to program integration by agency, indicating which agencies make a "broad-based" scientific contribution in each area and which agencies participate by making a more "focused" contribution.

For comparison with USGCRP budgets in years prior to FY98, two changes in the presentation of the USGCRP budget by agency should be noted:

The FY98 USGCRP budget request of $1.878 billion in this edition of *Our Changing Planet* is identical to that identified for global change research in the President's FY98 Budget. This differs somewhat from the USGCRP budget presented in previous editions in which there typically were some differences (explained in each edition) with the numbers presented in the President's Budget for the same year.

In general, the changes in this edition involve reclassifying as part of the USGCRP certain programs and activities in some agencies that were not previously included in the USGCRP budget as presented in *Our Changing Planet*.

The FY96 and FY97 budget figures in this edition of *Our Changing Planet* have been adjusted so that comparable programs are included throughout the compilation presented here for FY96, FY97, and FY98. The result is to make the USGCRP budget totals for FY96 and FY97 somewhat higher than those presented in previous editions.

In this edition of *Our Changing Planet*, the USGCRP budget is presented in two broad components: Scientific Research, and Space- Based Observation Programs. This change is intended to make clearer the portion of the USGCRP budget that supports scientific research by individual investigators and small groups, as compared with the portion that supports NASA's Mission to Planet Earth program components relating directly to space missions—particularly the Earth Observing System series of satellites and data information systems, which provide data in support of the research activities.

Of the total USGCRP FY98 budget request, 61% supports Space-Based Observation Programs while 39% supports Scientific Research. The FY98 request for $1.153 billion for Space-Based Observation Programs is a 2.8% increase from the FY97 budget; the $725 million request for Scientific research is a 5.4% increase from FY97.

Agency	FY96	FY97	FY98 Request
Scientific Research[a]			
Department of Agriculture (USDA)	52	57	61
Department of Commerce (DOC/NOAA, DOC/NIST)	58	60	62
Department of Energy (DOE)	113	112	110
Department of Health and Human Services (HHS)	4	4	4
Department of the Interior (DOI)	29	29	29
Environmental Protection Agency (EPA)	22	14	21
National Aeronautics and Space Administration (NASA)	271	240	264
National Science Foundation (NSF)	163	164	166
Smithsonian Institution (SI)	7	7	7
Tennessee Valley Authority (TVA)	1	1	1
Scientific Research Subtotal	**720**	**688**	**725**
Space-Based Observation Programs			
National Aeronautics and Space Administration (NASA)[b]	1090	1122	1153
U.S. Global Change Research Program Total[c]	**1810**	**1810**	**1878**

a

The Department of Defense (DOD), as part of its defense mission, supports research that is nevertheless relevant to the global change research activities of the civilian agencies. In past years, this has been reflected in the budget tables published in *Our Changing Planet*. The DOD budget for defense related research that nevertheless contributes to USGCRP activities follows: $6M (FY96), $9.8M (FY97), and $5.7M (FY98 request).

b

The NASA budget totals in this line include funding for all Mission to Planet Earth (MTPE) program components relating directly to space missions. In addition to these activities, a few additional programs that have not been included in the USGCRP budget as published in the FY97 and earlier editions of *Our Changing Planet* are now considered by NASA as supporting global change research. These budget items include Launch Services and the transfer of related Technology Applications Research from NASA's Office of Space Access and Technology into MTPE.

c

The USGCRP budget totals for FY96, FY97, and the FY98 request reported here include NASA MTPE budget components that were not included in the USGCRP budget as published in FY97 and earlier editions of *Our Changing Planet* (discussed in previous note). As a result, the USGCRP budget for these years in this table appears correspondingly higher.

The Kyoto Negotiations on Climate Change: a science perspective

Bert Bolin, 1998. The Kyoto Negotiations on Climate Change: a science perspective. *Science* **279**, pp. 330-331.

- Two cateogries of countries
  - Annex 1
  - Non-Annex 1(not required to take on specific commitments on greenhouse gas emissions)
- All key greenhouse gases not controlled by the Montreal Protocol would be included
  - Carbon Dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous Oxide (N_2O)
  - Hydroflurocarbons (HFCs)
  - Perfluocarbons (PFCs)
  - Sulfur Hexafloride (SF_6)
- Annex 1 countries will have to reach specified targets by 2010

- From 1990 to 1995 the EU decreased carbon dioxide emissions by ~1% while the rest of the Organization for Economic Cooperation and Development (OECD) increased emissions by about 0.8%.
- The targets agreed to for the Annex I parties by 2010 add up to a decrease in greenhouse gas emissions by ~5% below 1990 values.
- From 1990 to 1995 the total greenhouse emissions from non-Annex I parties increase about 25%. While this is not expected to continue an increase of ~4% per year would mean that by 2010 Annex I and non-Annex I parties would each contribute ~50% to total emissions (8.3 Gt)
- Estimated that the accumulated emissions from 1990 to 2010 will mean an addition of 140 Gt of carbon and an increase in atmospheric CO_2 levels by ~29 ppmv to ~382 ppmv. Annex I countries will account for 57% of this increase and non-Annex I for 43%

- The inertia of the climate system was not appreciated fully by the delegates in Kyoto. It thus seems that another international effort will be needed before 2010 to assess what future measures need to be taken.
- The third IPCC report will be available in early 2001.
- The supply of energy is fundamental to development, but the non-Annex I countries may be able to achieve development with less emissions if better efficiency can be achieved.
- The Kyoto conference did not achieve much with regard to limiting the buildup of carbon dioxide in the atmosphere. If no further steps are taken in the next 10 years, the increase in atmospheric carbon dioxide will continue to increase in the next decade essentially as it has done in the past few decades.